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INTEGRATED PEST MANAGEMENT IN INTENSIVE FORESTRY

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Abstract.--Multi-factored problems influencing growth and establishment of short rotation intensively cultured hybrid poplar plantations have been identified but solutions are obscure. Complete weed control can increase attacks by the tarnished plant bug (Lygus lineolaris), Melampsora medusae leaf rust, and some root pathogens. However, increased growth aided by complete weed control can reduce damage caused by deer and rodents.

Additional keywords: hybrid poplar, weed control, tarnished plant bug, deer browse, nutrient management, leaf rusts.

Short rotation intensive culture (SRIC) is an area of forest silviculture that has generated considerable interest in the past 2 decades. Most of the research interest and management application has been centered on hybrid poplars. Although the biology and technology is still in its infancy, more than 2,000 acres has been planted by a single forest industry in the United States (Morin, Personal Communication)[2/] and almost 6,500 acres by the Ontario Ministry of Natural Resources of Canada (Barkley, Personal Communication)[3/]. Intensive culture is often defined as establishing plantations using thorough site preparation, weed control, close spacings, short rotations, fast-growing genetically-improved trees, fertilization, and sometimes irrigation. Because of the fast growth and high yields, rotations are much shorter than those for the same species grown under natural forest conditions. The use of intensive culture practices, compressed rotation periods, monocultures with a single clone, high energy inputs, high biomass yields, and complete mechanization results in plantation management practices identical in principle to those of farming.

As the environment is manipulated to near its optimum for producing maximum yields, small stresses that previously were insignificant or incipient in nature sometimes expand into major problems. Because of the uniformity of material and environmental control in intensively cultured plantations, it is possible to observe relations that otherwise would not be noticeable in natural stands due to their enormous variability. In this paper we present four examples of relations between intensive management practices, site quality and pest problems (or benefits) that ensued. These examples are from short rotation intensively cultured hybrid poplar plantations at Harshaw Farm near Rhinelander in northern Wisconsin.

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CASE STUDIES

Minimizing tarnished plant bug damage[4/]

In 1978 we observed that an agent was injuring young hybid poplars. Each summer, lesions developed on the stems and occasionally on short branches, growing tips, and leaf petioles of certain clones of newly planted and 1- and 2-year-old poplars grown from cuttings. The injured areas sometimes calloused over but frequently stems were girdled or broken above the injury. Initially we speculated about whether the injury was due to insects or pathogens. Sapio et al. (1982) conducted a 2-year study that identified the causative agent as an injury response to feeding by the tarnished plant bug, Lygus lineolaris, (TPB) and that related the incidence and severity of damage to management practices. The following relations are extracted from this published paper.

A survey of existing poplar plantations indicated clonal differences in susceptibility of poplar clones to the TPB (table 1). Trees with lesions ranged from 0 to 43 percent depending upon clone. Other researchers have found that the TPB feeds on a range of hosts (Taksdal 1963). A survey of Harshaw Farm revealed 13 principal weeds that are also known hosts to the TPB (table 2). Several of these weeds are strong or moderate competitors of poplars. Horseweed and fleabane, which are prevalent weeds at Harshaw Farm, have been identified as principal wild hosts of the TPB (Larson et al. 1977; Tugwell et al. 1976). Observations throughout the farm indicated that TPB's were common on horseweed and that poplars had fewer lesions where horseweed was abundant. This suggests that preference for horseweed lowered the incidence of attack on poplars. A greenhouse test using caged TPB's on poplars with and without horseweed showed that the presence of horseweed was associated with a marked decrease in the number of poplar lesions.

Test	Lesions ($\bar{x}$)
poplar NC-9921	4.4
poplar NE-375	5.4
poplar NC-9921 and horseweed	0.4
poplar NE-375 and horseweed	0.4

In another test, 720 young trees were censused for lesions to determine effects of weed control on prevalence of lesions. The study contained three clones observed to be susceptible to lesions: NE-378, NE-1, and NC-9921. The six weed control treatments were as follows:

1. FURROW-CULTIVATION: cultivated 10 times during the first summer gradually filling in the furrow in which the trees were planted.

2. FURROW-CULTIVATION-CLOVER COVER CROP: similar to above except 12 lbs/ac white dutch clover (WDC) seed was applied by cyclone spreader after the eighth and final cultivation in late July.

3. LINURON-GLYPHOSATE: Linuron at 2 lbs active ingredient (ai)/ac was applied prior to planting. Glyphosate at 2 lbs ai/ac was applied in late July.

4/ The authors would like to acknowledge the work done by Frank Sapio on the tarnished plant bug. Much of this section was extracted directly from his publication.

4. GLYPHOSATE: herbicide was applied at 2 lb ai/ac twice in June and July with a shielded sprayer.

5. ROLLING-CULTIVATION: Cultivated over the tops of cuttings for first three cultivations and thereafter between the rows for a total of 11 cultivations.

6. CLOVER COVER CROP: Benefin was incorporated into the soil at 1.5 lb ai/ac prior to seeding 6 lb/ac WDC in mid-May.

Analysis of variance was highly significant for clone, treatment, and interaction. Average lesions per tree for the three clones were NE-386, 0.50; NC-9921, 0.22; and NE-1, 0.08. Clonal susceptibility ranking was the same as in the previous clonal trials (table 1). Number of lesions also differed by weed control treatment (fig. 1). Furrow-cultivated treatments with the fewest weeds had the most lesions per tree while treatments with only WDC had the least number of lesions. Poplars within herbicide, rolling cultivation, and WDC cover crop treatments had similarly low numbers of lesions. This was probably due to the similarity of the amount of vegetation in each treatment at crucial times for the TPB. Sufficient clover and weeds in the herbicide and rolling

Table 1.--Susceptibility of 20 Populus clones in a split stem lesion caused by the tarnished plant bug. Harshaw Research Farm, Rhinelander, WI.

Clonal Numbers			
Original	No. Cent. For. Exp. Station	Parentage	Percent trees with lesion[a/]
NE-298	NC-5332	Populus nigra var. betulifolia x P. trichocarpa	43
NE-386	NC-5263	P. 'Candicans' x (P. x berolinensis)	30
NE-387	NC-5262	P. 'Candicans' x (P. x berolinensis)	26
--	NC-9921	Populus sp.	20
--	NC-5351	Populus sp.	6
DN-34	NC-5326	P. x euramericana 'Eugenei'	3
--	NC-5277	P. x euramericana 'Wisconsin #5'	3
NE-1	NC-5272	P. nigra x P. laurifolia 'Strathglass'	3
--	NC-5258	Populus sp.	0
NE-372	NC-5266	P. deltoides var. angulata x P. trichocarpa	0
--	NC-5260	P. tristis x P. balsamifera 'Tristis #1'	0
DN-30	NC-5323	P. x euramericana 'Canada Blanc'	0
NE-252	NC-5334	P. deltoides var. angulata x P. trichocarpa	0
NE-299	NC-5331	P. nigra var. betulifolia x P. trichocarpa	0[b/]
--	NC-9922	Populus sp.	0[b/]
NE-375	NC-5264	P. deltoides var. angulata x P. nigra var. plantierensis	0[b/]
NE-388	NC-11505	P. maximowiczii x P. trichocarpa	0
I-476	NC-4879	P. x euramericana 'I-476'	0
DN-28	NC-5325	P. x euramericana 'Ostia'	0
--	NC-5339	P. alba x P. grandidentata	0

a/ 64 trees per clone, lesions from 1980 season.
b/ Moderate number of lesions in other field and greenhouse test plantings.

cultivation plots probably lured the TPB away from the poplars. In contrast, the furrow cultivation plots were free from vegetation for much of the summer thus leaving the poplars more vulnerable to attack.

An insecticide (malathion) has been used with mixed success for TPB on an agricultural crop (Pruess 1974). In a pilot test on poplars at Harshaw Farm a single application of malathion early in the season significantly reduced lesions. The early season spray probably killed most of the adults soon after they emerged from overwintering and before they laid many eggs.

Table 2.--Potential competitive level of the principal weed species at the Harshaw Research Farm that are hosts of the tarnished plant bug (TPB).

Common name	Scientific name	Potential competitive level[a/]
Lamb's quarters	Chenopodium album L.	High
Mustard	Brassica sp.	High
White cockle	Lychnis alba Mill.	High
Quack grass	Agropyron repens (L.) Beauv.	High
Horseweed	Erigeron (Conyza) canadensis (L.) Cronq.	Moderate
Daisy fleabane	Erigeron annuus (L.) Pers.	Moderate
Pigweed	Amaranthus sp.	Moderate
Canada thistle	Cirsium arvense (L.) Scop.	Low
Dandelion	Taraxicum officinale Weber	Low
Field-bindweed	Convolvulus arensis L.	Low
Goldenrod	Salidago spp.	Low
Ragweed	Ambrosia spp.	Low
Shepherd's purse	Capsella bursa-pastoris (L.) Medic.	Low

a/ Research data on file at USDA Forest Service, Forestry Sciences Laboratory at Rhinelander, WI.

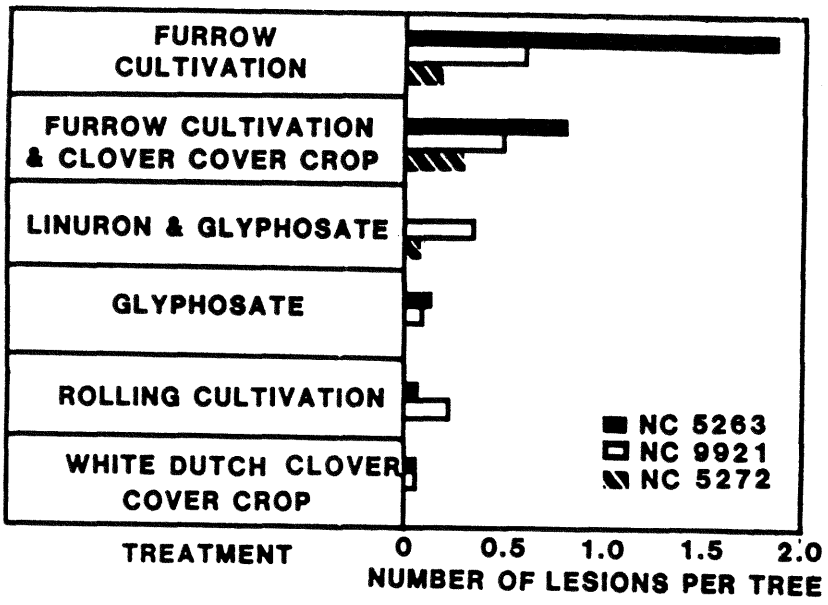

Figure 1.--Incidence of tarnished plant bug lesions on three Populus clones after various weed management treatments.

During the first two growing seasons after planting, poplars are more susceptible to TPB lesions. Lygus bugs, including the TPB, rarely fly more than 2 m above the ground (Mueller and Stern 1973). Therefore, the succulent tissue of the main stem of poplars is usually well out of reach after the second growing season. Feeding may still occur on lateral branches, but such lesions are inconsequential to poplar growth and biomass production unless they are extremely numerous.

These data and observations indicate a multi-faceted approach for minimizing TPB damage in young poplar plantations; 1) screen and select clones that are less susceptible to TPB feeding, 2) avoid clean cultivation -- either leave some TPB preferred weed species or use a preferred cover crop such as WDC, and 3) apply insecticides at the appropriate time to provide lasting protection for the season. Since completing this study, we have not had serious problems with the TPB even though we continue to use susceptible clones and have not used insecticides. Most likely our success is due to omitting clean cultivation. With proper management the TPB problem need only be a concern during the first 2 years of plantation establishment because the poplars rapidly grow out of the habitat frequented by the TPB's.

Nutrient management - pathogen relations

During the course of applying many different management practices to poplars, we observed pathogenic responses to some of these practices. Typically, these were observed and documented but not reported. We report two of the observed major responses here.

The first case involves the relations between weed control, tree nutrition, leaf rust, and tree height growth response. A dense growth of quackgrass, Agropyron repens, invading a poplar plantation during the first growing season was sprayed with glyphosate on July 29 using a tractor mounted shield sprayer (Hansen and Netzer 1985). Because we weren't certain that poplars could be shield sprayed during the growing season without serious herbicide damage or that we would get a beneficial growth response, the plantation was sprayed in 2 strips with alternating unsprayed strips. Within 2 weeks following the spraying, the quackgrass in the sprayed strips turned brown and the tree leaves were a significantly darker green color than those in the unsprayed strips.

At that time, as typically happens in the poplar plantations at Harshaw Farm, Melampsora medusae leaf rust began developing on the tree leaves. Infection severity was noticeably greater on the tree leaves in the sprayed strips and those trees defoliated earlier in the fall than did trees in the unsprayed strips. Foster (1967) states that although fertilizers that promote vigor reduce foliage diseases, excesses, deficiencies, and imbalances of nutrients have the opposite effect. A literature review by McNew (1960) on the effects of nutrition on plant foliage diseases concludes that nitrogen deficiency made 11 diseases worse and partially controlled 19. On the other hand, nitrogen excess made 58 worse and partially controlled 32. Tree height measurements in our study showed that during the remainder of the summer height growth was significantly less on trees in the sprayed strip. By the end of the second growing season, height growth was the same for both treatments. Our interpretation of these responses is that eliminating the quackgrass increased the availability of nitrogen and the trees responded by increasing nitrogen uptake. The higher nutrient content of the leaves provided a more fertile medium for Melampsora, which colonized the leaves earlier and resulted in

earlier defoliation. Although the experimental design does not exclude the possibility that the change in leaf color, Melampsora infection, and early defoliation was the direct effect of the glyphosate and not a relation between nutrition and pathogens, based on other spray tests we have conducted we judge that possibility to be less likely. Eliminating grass competition and increasing available nutrients and moisture would be expected to result in increased tree growth. In this instance, increased nutrients resulted in an increase in leaf nitrogen content. However, the increased severity of Melampsora infection together with early defoliation apparently offset any potential growth increase. Apparently, an expected growth increase from controlling competition may not materialize if the resulting environment is significantly more favorable for a pathogen.

The second case involves the relation between fertilization, a possible root pathogen, tree mortality, and biomass yield. The results are from a 5-year study in which we investigated the effect of annual applications of nitrogen fertilizer and several cover crop treatments on poplar biomass yield on a fertile silt-loam and an infertile sand site (Hansen and Tolsted 1985). Survival was 100 percent the first 2 years and still averaged 98 percent on the sand site at the end of the fifth year. However, trees began to die in the third year on the silt loam site and mortality was 20 percent by the fifth year. As shown in the following tabulation, almost all mortality on the silt loam site occurred on fertilized plots.

fertilizer	mortality	
	silt loam	sand
kg/ha/yr	- - - percent - -	
0	4	1
0	0	3
0	17	0
56	32	8
112	16	1
112	24	1
112	24	1
112	28	1
168	21	7

This pattern of increased mortality with fertilization had been noted for several other clones at Harshaw Farm. Typically, symptoms begin on 3-year-old trees. Leaves along the tree stem flush profusely, leaves on the branches flush late, and trees die within a year. Mortality is generally greatest when fertilization is combined with good weed control. Nutrient status seems to be the common underlying factor in the mortality patterns. Nitrogen stimulates germination of the resting stages of fungi, favors growth of the harmful species of root-attacking fungi and restricts the growth of their natural enemies (Sadasivan 1965; Schroth and Hildebrand 1964). Foster (1967) concludes that high concentrations of nutrients build an adequate food base for fungi and raise the inoculum potential high enough to attack mature roots (Rennerfelt and Tamm 1962, Garrett 1956, 1959). We speculate that nitrogen fertilization of an already fertile silt-loam site resulted in nitrogen levels that favored fungi that caused tree mortality. In this case, even though fertilization resulted in increased mortality, biomass yields still increased (table 3). But biomass yields would have been even greater if mortality had not occurred. From this case we conclude that inherent site fertility, nutrient drain from weed competition, and nutrient inputs from fertilization must be balanced so that

fertility is optimized for the poplars and not for competing pathogens. We hypothesize that this problem may be reduced or avoided altogether by selecting clones or perhaps by carefully monitoring nutrient levels with a tissue bioassay.

Table 3.--Relation of mean annual biomass production to fertilization in 5-year-old poplar plantations on a silt loam and a sand site. Treatments next to a common line are not significantly different. The ANOVA for the silt loam site was not significant.

silt loam		sand	
fertilizer kg/ha/yr	biomass Mg/ha/yr	fertilizer kg/ha/yr	biomass Mg/ha/yr
112	7.6	168	6.7
168	6.5	112	6.4
112	6.2	112	5.8
56	5.7	112	5.1
112	5.4	56	2.8
0	4.8	0	1.8
0	4.2	0	1.6

Minimizing deer browse

Browsing by white-tailed deer (Odocoileus virgineanus) is a major problem when establishing intensively cultured hybrid poplar plantations (Netzer 1984, Hansen et al. 1983). We evaluated the relation of deer browsing in terms of clonal preference, preferred browsing height, season, and the impact on subsequent tree growth in two separate studies.

In the first study 13 hybrid poplar clones were planted in 3 replications in an old field site adjacent to a natural woodlot frequented by deer (Netzer 1984). Tree survival, total height, and deer browse incidence were recorded at the end of the first growing season in September 1979 and again in May 1980 after a winter of heavy browsing. The length of the shoot tip removed by browsing was determined by subtracting the spring height from the fall height.

Certain clones were significantly preferred ($p = 0.01$) during late summer-early fall browsing (table 4). However, by spring browsing was not significantly different due to clone. Also, the length of shoot removed by browsing was not significantly different between clones. Approximately 8 to 10 cm were browsed from the terminal of all clones tested. In earlier trials with penned deer, it was found that deer consumed leaves of two of five clones before feeding on the other three. However, over a longer period (8 to 24 hours) the deer consumed the leaves of all five clones (Verch 1979).

In the second study a 2.8 hectare old field site was planted in spring 1980 with a hybrid poplar clone P. deltoides x P. trichocarpa (Netzer 1984). Ten to 15 deer frequented the site from the time of planting, often bedding down in the plantation. A 200-tree subplot was selected in the center of the plantation to measure total tree height and deer browse incidence on September 16, 1980, May 12, 1981, and September 22, 1981.

Table 4.--Deer browsing preference for 13 hybrid poplar clones during the first growing season as measured on September 25, 1979 (clones next to a common line are not significantly different).

Clone			
Original number	No. Cent. number	Parentage	Percent browsed
NE-298	5332	P. nigra var. betulifolia x P. trichocarpa	85
NE-252	5334	P. deltoides var. angulata x P. trichocarpa	53
NE-1	5272	(P. nigra x P. laurifolia) 'Strathglass'	50
NE-386	5263	P. 'candicans' x (P. x berolinensis)	48
--	5260	(P. tristis x P. balsamiferia) 'Tristis #1'	38
--	5351	Populus spp.	27
--	5258	Populus spp.	23
DN-30	5323	P. x euramericana 'Canada Blanc'	23
NE-299	5331	P. nigra var. (betulifolia x P. trichocarpa)	22
--	5377	P. euramericana 'Wisconsin #5'	21
NE-372	5266	P. deltoides var. angulata x P. trichocarpa	19
DN-28	5325	P. x euramericana 'Ostia'	18
NE-375	5264	P. deltoides var. angulata x P. nigra var. plantierensis	13

Deer browsed 55 percent of the trees in the 200-tree plot by the end of the first winter. Trees of all heights were browsed, but tall trees were browsed less. Only 24 percent of the trees more than 1.6 m tall were browsed compared with 70 percent of those less than 1.3 m (fig. 2). During the second year, browsed and unbrowsed trees had the same growth (table 5). Total tree height at the end of the second growing season was 290 cm for the browsed trees and 303 cm for the unbrowsed trees. The average amount browsed by deer was 10 cm. This accounts for most of the 13 cm difference. The impact of browsing on subsequent tree growth showed no relation to the initial tree height.

Early in the season when food is plentiful, browsing deer prefer certain clones as illustrated here and in a study by Verch (1979) with penned deer. However, by the end of winter all clones tested were browsed equally. Judging from our experiences with 13 different clones, it will be difficult to identify clones resistant to deer browsing. An alternative to selecting unpalatable hybrid poplar clones is to plant fast-growing clones using the best means of plantation establishment. Well-established hybrid poplar plantations are still likely to be browsed during the first year but should grow above the reach of feeding deer the second year. Poorly established plantations will grow slowly, allowing deer to browse for several years.

Multiple factor problems

The previous examples described situations where only two or three factors interacted. Often problems are much more complex so that it is difficult to perceive what is happening let alone take decisive management action to correct the problem. One such interaction that we have observed is between weed control, fertilization, rodent damage, and tree lodging.

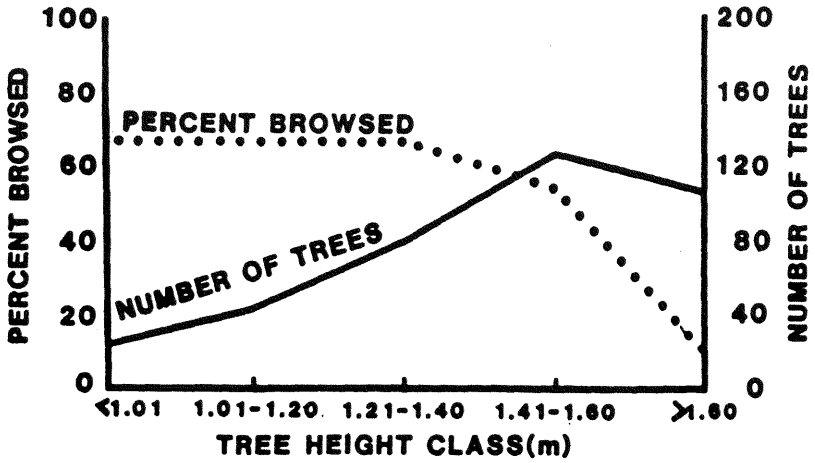

Figure 2.--Percent of hybrid poplars browsed by height class. Height class is based on tree height at the end of the first growing season prior to any deer browsing.

Generally, good weed control is desirable. Numerable studies have demonstrated that removing weeds reduces competition for moisture and nutrients and results in greater tree growth. With good weed control, fertilizing is not necessary the first few years on fertile sites (Hansen and Tolsted 1985). Preventing a dense cover of weeds also greatly reduces the risk of damage from rodents girdling trees. On the other hand, removing all weed cover during the first few years of plantation establishment results in high rates of soil mineralization with consequent loss of nitrogen from the soil (McLaughlin et al. 1985). To reduce this loss it may be desirable to maintain some herbaceous cover on the site. Another problem that is sometimes associated with complete weed control is lodging of the trees. We have had problems with tree lodging in some plantations--always when there was no herbaceous ground cover. Evidently, herbaceous ground cover provides a root mat that helps anchor weakly rooted poplar clones. Also, eliminating weeds results in more available nutrients and consequently larger tree crowns. Some clones have never lodged though, indicating that rooting habit and crown size may differ significantly between clones.

These sort of relations have not been studied in designed tests and some may never be studied. Lodging depends in part on weather patterns, which are not controllable. Likewise, rodent populations are difficult to study in a semi-controlled field experiment. Consequently, observational accounts of multi-factor problems such as just described here may be the norm. Our knowledge may depend on a series of well-documented case studies.

DISCUSSION

Intensive culture of forest plantations involves manipulating the environment to near its optimum. Because of the uniformity of the site and the intensity of the practices, problems that are usually obscured in forest management sometimes become conspicuous. Problems that appear to involve only two or three factors may be corrected through management. However, it may be that all pest problems are extremely complex and that we fail to recognize all the factors. Solutions to multi-factored problems are obscure. For example,

herbaceous weed cover was a common factor in all of the previous examples. Complete weed control is desirable for rapid tree growth to minimize the duration of deer browsing, to attain high yields, to reduce fertilizer needs, and to minimize risk of rodent damage. On the other hand, some weeds may be desirable to provide a preferred alternate host for some insects, to reduce soil mineralization and consequent nitrogen loss, and to prevent tree lodging. The best level of herbaceous cover to manage for will depend upon pests, soils, clone, weather, and the type of environment surrounding the plantation. We do not know what a "best" level is for a particular site, how to go about determining that level, or once we determine it how to actually manage for that level of herbaceous cover. Integrated pest management in intensive culture (or traditional forest management) will involve simultaneously considering a large array of inter-related factors. We are only beginning to identify some of the more obvious factors. But this identification is an important first step to solving the problem.

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